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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



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## TECHNICAL MEMORANDUM

No. 1148

LIFT INCREASE BY BLOWING OUT AIR, TESTS ON AIRFOIL OF  
12 PERCENT THICKNESS, USING VARIOUS TYPES OF FLAP

By W. Schwier

Translation

“Versuche zur Auftriebssteigerung durch Ausblasen von Luft  
an einem Profil von 12 <sup>0</sup>/<sub>0</sub> Dicke mit verschiedenen  
Klappenformen”

Deutsche Luftfahrtforschung, Forschungsbericht Nr. 1658



Washington

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LIFT INCREASE BY BLOWING OUT AIR, TESTS ON AIRFOIL OF  
12 PERCENT THICKNESS, USING VARIOUS TYPES OF FLAP\*

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SUMMARY

The NACA 23012-64 airfoil was investigated for the purpose of increasing lift by means of blowing out air from the wing, in conjunction with the effect of plain flap of variable contour and slotted flap of 25-percent chord length. The wing also was provided with a hinged nose, to be deflected at will. Air was blown out from the wing immediately in front of the flap; also at the opening between wing and hinged nose,<sup>1</sup> tangentially to the surface of the wing. Another device employed to increase maximum lift was a movable slat, to be opened to form a slot.

Lift was measured in relation to the volume of blown-out air and considerable increases were observed with increasing volume.

The slotted flap was provided with pressure tubes. In order to determine moments, normal and tangential forces on the flap, pressure distributions were taken at several angles of attack and various deflections of the flap.

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\*Versuche zur Auftriebssteigerung durch Ausblasen von Luft an einem Profil von 12 % Dicke mit verschiedenen Klappenformen, Zentral für wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (ZWB) Berlin-Adlershof, Forschungsbericht Nr. 1658 Göttingen, Sept. 15, 1942.

<sup>1</sup>Translator's Note. From the German "Knicknase."

## I. INTRODUCTION

The present report on blowing tests on an NACA 23012-64 airfoil is one of a series of papers on various airfoils for the purpose of increasing lift by blowing out air. Up to the present, reports in this series include tests on an airfoil of 18 percent thickness (1), a symmetrical airfoil of 12.8 percent thickness (2) and of 9 percent thickness (3). A further report is now being prepared on tests on an NACA 23015 airfoil.

The tests contained in the report at hand encountered the particular interest of the Messerschmitt company and in part were carried out with their support.

## II. STATEMENT OF THE TEST PROBLEM

The problems of this investigation are substantially corresponding to those stated in studying the airfoil of 9 percent thickness and are more fully discussed in the thereto pertaining report.

The problems consist of increasing lift to the highest attainable value, determination of effects of slot and flap and of hinged nose and flap to the best advantage of lift as well as observation of effect of blown-out air on the lift. To obtain information concerning the moments applied to operate the flap, the forces acting upon the latter are to be obtained in relation to the volume of blown-out air.

## III. DESCRIPTION OF MODELS AND TEST PROCEDURE

The tests here discussed have been performed on the NACA 23012-64 airfoil, with maximum thickness at 40-percent chord and leading-edge radius of the normal size. The airfoil, whose coordinates are taken from NACA Rep. 610 (4), is shown, with the above mentioned high-lift devices, in figures 1 and 2.

The types of flap represented in figure 2 were tested a few months after those shown in figure 1. The type employed first was a plain flap, figure 1, type a, of 24-percent chord length (with respect to wing chord) measured from hinge to trailing edge. This flap has been designed with an offset in the forward

section (on the suction side). This was done in order to obtain the shape of blowing slit thought to be of best advantage as well as insure thorough tightness of the slit with the flap in streamlined position. However, the offset proved to have adverse effects on blowing of air upon the flap, therefore, it was evened out by covering it up with sheetmetal (fig. 1, type b). Later on, flaps type c and d, figure 1 were produced by applications of plastiline to that section, thus obtaining a thicker contour. These have been termed "moderately thickened" (type c) and "heavily thickened" (type d).

In further tests the wing was provided with a plain flap of 24 percent and a slotted flap of 25-percent chord length (fig. 2). To determine the best position of the hinge of the slotted flap during blowing out air, this position was variable within wide limits. The hinge of the plain flap at first was fixed; however, in course of the tests it became expeditious to displace it to some extent.

Air was blown out from the wing just forward of the flap; a change in width of the blowing-out slit was accomplished by interchanging the aft wing section.

Other means provided at the nose section to increase lift include a slat of 13 percent and a hinged nose of 17.5-percent chord length. Position of the slat was variable according to the series of holes shown in figure 1, changing the width of slot formed by the slat at the same time. Construction of the hinged nose was such that by deflecting the latter a slit was formed between hinged nose and the main wing surface, from which air could be blown out in a direction tangential to the wing surface.

The inside of the wing has been subdivided by a diagonal wall into two airtight partitions in such a manner that air was blown out from one partition just forward of the flap and from the other immediately aft of the hinged nose.

The chord length of the wing model is  $l = 0.3$  meter, the span  $b = 1.2$  meters and it has been provided with end plates of 0.53-meter diameter.

The already established method has been followed in the tests. First the volume of blown-out air is increased to a high value, maintaining unseparated flow in the procedure as concluded from tuft observations. In the next step this volume is reduced taking lift measurements at the same time. In order to find any existing difference between the effect of decreasing and increasing

volume in the  $c_a(cq)$  relation, in some instances lift was determined at increasing volume as well.

Although drag was concurrently determined by the drag balance, the corresponding measurements are here not reported due to the inherent inaccuracy of the test procedure with respect to drag.

The slotted flap has been provided with pressure tubes located at the center of the span, which served to determine the moments on the flap during blowing out air. The position of the tubes is shown in figure 2(a), representing the slotted flap apart from the wing. In order not to affect force measurements by the pressure tubes protruding from the wing, pressure distributions on the flap were obtained in separate tests.

#### IV. SYMBOLS AND EVALUATION

##### Symbols Used in Evaluating the Measurements

A	total lift in kilograms, measured by balance
M	pitching moment of wing in meter-kilograms, with respect to 0.25-chord point of wing
$N_f$	normal force acting on flap, in kilograms
$T_f$	tangential force acting on flap, in kilograms
$M_f$	moment acting on flap with respect to hinge of flap, in meter-kilograms
v	velocity of blower stream in meters/second
$v_a$	mean velocity of blown-out air at outlet in meters/second
F	0.36 square meter, wing surface with closed flap and closed slat
l	0.3 meter, wing chord with closed flap and closed slat
b	1.2 meters, wing span of model
$F_f$	flap surface, taken from hinge to trailing edge, in square meters
$l_f$	length of flap, taken from hinge to trailing edge, in meters

- $l_v$  length of slat, taken parallel to wing chord, in meters  
 $l_N$  length of hinged nose in meters  
 $s$  width of blow-slit at the flap in meters  
 $s_N$  width of blow-slit at hinged nose in meters  
 $s_v$  width of slot (between slat and wing) in meters  
 $Q$  volume of air blown out at flap in cubic meters/second  
 $Q_N$  volume of air blown out at hinged nose in cubic meters/second  
 $p, p_N$  excess pressure in wing required for blowing out the volumes  $Q$  and  $Q_N$ , respectively, in kilograms/square meter

$$c_a = \frac{A}{\frac{\rho}{2} v^2 F}; \quad c_M = \frac{M}{\frac{\rho}{2} v^2 F l}; \quad c_r = \frac{M_r}{\frac{\rho}{2} v^2 F_r l_r}$$

$$c_{Nr} = \frac{N_r}{\frac{\rho}{2} v^2 F_r}; \quad c_{Tr} = \frac{T_r}{\frac{\rho}{2} v^2 F_r}$$

$$c_Q = \frac{Q}{v F}; \quad c_{QN} = \frac{Q_N}{v F}; \quad c_p = \frac{p}{\frac{\rho}{2} v^2}; \quad c_{pN} = \frac{p_N}{\frac{\rho}{2} v^2}$$

$\alpha$  geometrical angle of attack, taken between wing chord and wind-tunnel axis

$\alpha_\infty$  angle of attack for infinite aspect ratio and infinite jet dimensions

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<sup>a</sup> Translator's Note. The above coefficients will be recognized as lift coefficient ( $c_a$ ), moment coefficient ( $c_M$ ); while the others may be denoted as moment coefficient of flap ( $c_r$ ), normal-force coefficient of flap ( $c_{Nr}$ ), tangential coefficient of flap ( $c_{Tr}$ ),  $c_Q$  and  $c_{QN}$  are coefficients of the blown-out air volume and  $c_p$  and  $c_{pN}$  coefficients of internal pressure.

$\eta$  flap deflection  
 $\eta_N$  hinged nose deflection  
 $\Lambda$  aspect ratio  $\left(\frac{b^2}{F}\right)$

Conversion of  $\alpha$  to  $\alpha_\infty$ :

- (1) Correction applied for finite jet dimensions:

$$\alpha_{1K}^0 = \alpha_a \times 0.654^\circ$$

(Calculated according to Göttinger Lieferung, page 12.)

- (2) Correction applied for finite aspect ratio:

$$\alpha_i^0 = K \frac{\alpha_d}{\Lambda} \times 57.3^\circ$$

The factor  $K$  applied to correct for wing with end plates; the value for the end plates used was determined experimentally (5). With this value:

$$\alpha_i^0 = \alpha_a \times 2.811^\circ$$

Deducting  $\alpha_{1K}$  and  $\alpha_i$  from  $\alpha$  the total correction becomes:

$$\alpha^0 = \alpha - \alpha_\infty^0 = \alpha_a \times 3.465^\circ$$

The drag coefficient  $c_w$  has been used to calculate  $c_M$  from lift and drag measurements. Although, as mentioned above,  $c_w$  could be determined with poor accuracy, its influence in calculating pitching moments is small compared to that of lift and has been allowed to be taken into account.

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<sup>3</sup> Translator's Note. The formula for  $\alpha_i^0$  is taken from part 9 of this series of reports. It is incorrectly quoted in the original of this report (page 6 of the German text).

The moment coefficient of flap is found from pressure distributions using the equation

$$c_r = \int \frac{p}{q} \frac{z}{l_r} d\left(\frac{z}{l_r}\right) - \int \frac{p}{q} \frac{x}{l_r} d\left(\frac{x}{l_r}\right)$$

where the first term represents moment of the tangential, the second term that of the normal-component forces. Using the signs as given in the equation, the moment is positive for a positive tangential force above, and for positive normal force forward, of the flap hinge. The integrals are determined by plotting  $\frac{p}{q} \frac{z}{l_r}$  and  $\frac{p}{q} \frac{x}{l_r}$  as functions of  $\frac{z}{l_r}$  and  $\frac{x}{l_r}$ , respectively, and evaluating the areas under the corresponding curves with the planimeter.

The normal and tangential force coefficients are obtained in similar manner, from pressure distributions with the equations

$$c_{Nr} = \int \frac{p}{q} d\left(\frac{x}{l_r}\right)$$

$$c_{Tr} = \int \frac{p}{q} d\left(\frac{z}{l_r}\right)$$

The theoretical lift coefficients  $c_{a_{th}} = f(\alpha)$  is included in the diagrams for comparison of the experimentally obtained results. The values for the theoretical curve are calculated (Walc (6)) for a streamlined airfoil (without flap) from

$$c_{a_{th}} = 6.95 \sin(\alpha^{\circ} + 1.29)$$

Deviations of the theoretical curve due to deflected flap are calculated according to Keuns (7).



## V. TEST RESULTS

Only the most prominent results are included in this report, contained in figures 3 to 35. From numerous observations, the relation  $c_a(c_Q)$  for various values of  $\alpha = \text{constant}$   $c_a(c_M)$  also for various values of the geometrical angle of attack  $\alpha = \text{constant}$  and the curves  $c_a = f(\alpha_\omega)$  for various values of  $c_Q = \text{constant}$  appear in all the diagrams from figure 6 on. It should be observed that along the curves  $c_a(c_M)$  the value of  $c_Q$  is not constant, but increases with  $c_a$ . The corresponding  $c_Q$ -value can be found on the  $c_a(c_Q)$  curve; the values of  $c_a(c_M)$  for various  $c_Q = \text{constant}$  are indicated by dotted line.

Figure 3 represents  $c_a = f(\eta_N)$  for the wing provided with a flap as in figure 1, type a. The optimum deflection of the hinged nose, without blowing air from the wing, was determined by finding  $c_{a_{max}}$  at flap deflections  $\eta = 0^\circ$  and  $\eta = 30^\circ$  and at various angles of attack ( $\alpha = \text{constant}$ ) for varying hinged nose angle. From the latter tests optimum of the hinged nose angle is at  $\eta_N = 15^\circ$ ; It must be stated that the increase due to the effect of this device is relatively small.

Effect of blowing out air at the hinged nose is shown by the diagrams of figure 4. The lift coefficient is obtained as function of the blown-out volume at the hinged nose ( $c_{QN}$ ) for constant flap deflection ( $\eta = 30^\circ$ ) and constant blown-out volume at the flap ( $c_Q = 0.0195$ ), varying the hinged-nose deflection. The curves  $c_a = f(c_{QN})$  in figure 4 are always given for that angle of attack, where at highest  $c_{QN}$  the flow is still definitely unseparated along the wing and flap. When this volume is reduced, gradual separation of flow appears on the wing.

It is evident that at the applied deflections of hinged nose, unseparated flow along the wing could be maintained and  $c_a$  increased considerably by the air blown out at the hinged nose. It will be noted, however, that a smaller volume of blown-out air is required to obtain the same and higher values of  $c_a$ , by comparing with tests for open-slat position and air blown out at the flap only (fig. 7 ( $\eta = 35^\circ$ ) and fig. 18). The conclusion of the tests discussed is that a slat has a more favorable effect than a hinged nose. Due to this fact, the remainder of these tests apply to the wing unaltered nose-section and with slat.

Tests including various positions of the slat (with flap type a, fig. 1) at flap deflections  $\eta = 0^\circ$  and  $\eta = 30^\circ$ , with-out air being blown out, are represented by figure 5. For  $\eta = 30^\circ$

the optimum position of the slat was found to be 7e (denoting position of the point of reference, fig. 1), with slat and wing forming a slot 14 millimeters wide. With closed flap the optimum position, in the upper diagram, figure 5, is only slightly different from 7e (14) (position 7e, slot 14 millimeters).

The optimum slat position was determined in a further test at open flap, with air being blown out at the flap; as above, the best position found in this case was 7e (14). The corresponding diagrams are not included in this report.

### PLAIN FLAP

With the best slat positions thus available,  $c_a = f(c_q)$  was then determined at various angles of attack using the types of flap shown in figure 1. These measurements are represented by figures 6 to 8. Only a slight increase in  $c_a$  could be attained by blowing when the offset flap was used (fig. 1, type a), therefore tests with this type of flap have been discontinued. Results of tests made are not shown in the report.

Air blowing produced considerably improved effects with the offset filled in (fig. 1, type b); the corresponding measurements are contained in figure 6. Unseparated flow along the flap could be maintained to a maximum flap deflection of  $\eta = 35^\circ$ ; the results shown are for this angle.

Information gained from tests on an airfoil of 9 percent thickness (reference 3 page 8) made it probable that more advantageous  $c_a(c_q)$  curves could be obtained with a flap, which when in open position, follows the original contour of the airfoil nearer to the blowing-out slit, than with one of figure 1, type b. Therefore a layer of plastiline was applied to the flap, producing the type "moderately thickened" (fig. 1, type c). Using this type, the flow could be kept unseparated around the flap by air-blowing up to  $\eta = 40^\circ$ . The test results, shown in figure 7 for the maximum obtainable angle of attack with unseparated flow was still being maintained, indicate in comparison to figure 6 that, for equal values of  $c_q$ , the lift coefficients are higher in the latter case.

By building up the flap further (fig. 1, type d), resulting in the "heavily thickened" type, unseparated flow along the flap could be maintained up to  $\eta = 45^\circ$ . The corresponding measurements, represented by figures 8 and 9, show that compared to type c to c' effective deflection angle of the flap was increased still more, with a corresponding increase in lift coefficient at equal values of  $c_q$ .

Flaps type c and d, obtained by building up the thickness with plastiline, had the experimental disadvantage that flap deflection could be varied within very narrow limits only. Tests on type d were restricted to  $\eta = 45^\circ$ . In order to obtain measurements for a wider range of flap deflections, the tests on types in figure 1 were soon discontinued. The wing was rebuilt and provided with a plain flap as in figure 2, type e. Beside the latter type, tests were run with the slotted flap (fig. 2, type f). The tests on types e and f followed a few months after the ones described above had been completed.

In using the plain flap (fig. 2) care had to be taken that there should be no break in contour caused by the contour of the opened flap falling below that of the original airfoil.

Results of tests with this flap, for  $\eta = 45^\circ$  and closed slat, are contained in figure 10, at the same width of the blowing-out slit as in figures 8 and 9 ( $s = 0.00667$ ). Comparison with figure 8 indicates that values of  $c_a(c_q)$  are about the same as those obtained with the "heavily thickened" flap (type d).

To find the effect of the width of the slit, the same type of flap was tested with a narrower slit ( $s = 0.00551$ ) likewise with closed slat and at  $\eta = 45^\circ$  and the  $c_a(c_q)$  relationship determined. The resulting  $c_a$  - values, as it was expected, are somewhat higher, using the narrower slit, at equal  $c_q$  (fig. 11). Naturally, the corresponding values of  $c_p$  are increased as well.

Observations of flow around the flap indicated that still higher values of  $c_a$  (at equal  $c_q$ ) may be obtained by shifting the flap toward the suction side. The flap was therefore so shifted that it extended somewhat beyond the wing contour of the suction side, at the same time however, for constructional reasons, it had to be displaced aft to some extent. These displacements amount to 1 millimeter ( $0.00331$ ) toward the suction side and 0.5 millimeter ( $0.00166$ ) aft. It is seen from a comparison of figures 10 and 15 that  $c_a$  is further increased by shifting the flap.

The remainder of the tests with plain flap (figs. 12 to 19) have been conducted with the flap in the latter position. Again the first thing determined was the most advantageous slat position, which is slightly different from the previous position. The best results for the rebuilt wing are for slat position 6e (16). (See page 6 for designation.) The measurements are not shown in detail.

The general results agree with those from earlier tests on other airfoils and flaps with air-blowing arrangement. For small deflections of flaps the increase in  $c_a$  with the blown-out volume is relatively

small. At larger deflection angles ( $\eta = 30^\circ$  and  $45^\circ$ ) and low values of  $c_Q$ , the value of  $c_a$  first decreases below that for  $c_Q = 0$ , comes to a minimum, then increases considerably with  $c_Q$ . A marked increase always begins when  $c_Q \approx 0.006$  to  $0.007$ , corresponding to the equation giving the ratio of mean blowing-out velocity  $v_a$  to airspeed  $v$ :

$$\frac{v_a}{v} = c_Q \frac{l}{s} = 0.9 \text{ to } 1.05$$

Also this is in agreement with earlier tests.

It appears from the theoretical curves  $c_{a,th}$  in the  $c_a(\alpha_\infty)$  diagrams, that with increasing  $c_Q$ , the experimental values more and more approach the theoretical lift coefficients. Already at  $c_Q = 0.020$  and even at  $c_Q = 0.015$  for small flap deflections, the experimental and theoretical values are in close agreement. In some cases the experimentally obtained lift coefficients even exceed the theoretical values.

This fact is easily understood by realizing that the momentum of blown-out air adds a component in the direction of lift and that at high blowing velocities the effective chord length of the wing may be considered increased due to the blown-out jet of air.

Also, if the trailing edge is not perfectly well defined, with the great energy being conveyed to the boundary layer by blowing-out of air, displacement of the stagnation point beyond the position otherwise determined by the trailing edge will sometimes take place, causing  $c_a$  to increase.

Which of these factors is predominant in the increase of lift beyond its theoretical values, is a question still in need of closer investigation.

It is seen from the  $c_a(c_Q)$  curves that while at constant  $\alpha$  and increasing  $c_Q$  the lift coefficient increases considerably, no systematic variation occurs in the curves  $\frac{dc_a}{d\alpha}$ , that is the slope of the  $c_a(\alpha_\infty)$  function. Furthermore, the angle of attack of maximum lift seems to become smaller as  $c_Q$  increases.

Figures 15 and 19 give, for example, the following  $c_a$  increases, with plain flap (fig. 2, type e) at  $\alpha_\infty = \text{const}$ :

## PLAIN FLAP

$\eta = 45^\circ$		$c_Q$	0	0.010	0.015	0.020
$\alpha_\infty = -5^\circ$	Slat closed	$\Delta c_a$	0	0.27	1.11	1.65
	Slat opened	$\Delta c_a$	0	0.45	1.17	1.71

The following table contains values of the quantity  $\frac{\partial a}{\partial \eta}$ , denoting flap effectiveness. These are taken from the  $c_a(\alpha_\infty)$  curves at constant lift,  $c_a = 1$  and since they were determined over a range of deflections from  $\eta = 0^\circ$  to  $45^\circ$ , represent mean values for that range of  $\eta$ .

## PLAIN FLAP

	$c_Q$	0	0.010	0.015	0.025
Slat closed	$\frac{\partial a}{\partial \eta}$	-0.299	-0.305	-0.455	-0.553
Slat open	$\frac{\partial a}{\partial \eta}$	-0.271	-0.322 <sup>4</sup>	-0.468	-0.549

These values show a sizeable increase in  $\frac{\partial a}{\partial \eta}$  as the volume coefficient  $c_Q$  becomes greater. There is no significant difference between the values for a wing with open slat and those with slat closed. Should these values be compared to the corresponding  $\frac{\partial a}{\partial \eta}$  obtained with flaps with no boundary-layer control, it is emphasized that the values obtained in the latter case apply to a very limited range of deflections, while those in the table here given are taken for the entire range of  $\eta = 0^\circ$  to  $45^\circ$ .

Glauert's theory gives  $\frac{\partial a}{\partial \eta} = -0.60$  for a flap having equal chord length to the one tested.

Effect of a slat, together with that of blowing out air at the flap, is substantially the same as the effect of slat only, with the customary plain flap. It consists of widening the range of effective angle of attack toward larger angles, thereby increasing  $c_{a_{max}}$ .

<sup>4</sup> Translator's Note: Presumably -0.322.

## SLOTTED FLAP

The first objective was, as above, to find the optimum hinge position of the slotted flap during blowing out air. Detailed results of this investigation are omitted. Highest values of  $c_a$  (at equal  $c_j$ ) were obtained when the hinge was shifted 1 millimeter (0.0033 ft) toward the suction side and at the same time 5 millimeters (0.0167 ft) aft, as compared with the original position. It is again characteristic that as in the former tests, the upper flap surface extends somewhat beyond the original contour of the airfoil.

Test results with slotted flap, for slat open as well as closed, are shown in figures 20 to 27. The  $c_a(c_j)$  relationships are not fundamentally different from those pertaining to the plain flap, although, for corresponding values of  $c_j$  the  $c_a$  values are throughout higher for the slotted flap. It should be considered that slits for blowing out air were narrower in the latter case.

Figures 23 and 27 yield the following  $c_a$  - increases, at constant angle of attack and constant flap deflection:

## SLOTTED FLAP

$\eta = 45^\circ$ $\alpha_\infty = -5^\circ$		$c_j$	0	0.010	0.015	0.020
	Slat closed	$\Delta c_a$	0	0.48	1.4	2.12
	Slat open	$\Delta c_a$	0	0.57	1.45	2.20

For purpose of comparison the following results of test on a 23012 airfoil with suction - type flap are quoted from a report by Regenscheit (8). These are, though, referring to a flap with a chord length of only 20 percent wing chord. The increase in lift coefficients are based on the values of  $c_j = 0$  (page 6)

$$c_j = 0.015 \quad \Delta c_a = 1.3$$

$$c_j = 0.020 \quad \Delta c_a = 1.4$$

Considering that the flap used in the suction tests is of shorter chord length, it may be stated that about equal results were obtained for  $c_j = 0.015$ , while at  $c_j = 0.020$  lift is increased more by blowing than by suction.

Values of  $\frac{\partial a}{\partial \eta}$  for slotted flap are given in the table below, obtained from the  $c_a(a_\infty)$  curves at  $c_a = 1$  and for  $\eta = 0^\circ$  to  $45^\circ$ .

SLOTTED FLAP

	$c_j$	0	0.010	0.015	0.020
Slat closed	$\frac{\partial a}{\partial \eta}$	-0.293	-0.329	-0.467	-0.541
Slat opened	$\frac{\partial a}{\partial \eta}$	-0.270	-0.277	-0.478	-0.601

The above values for  $c_j = 0.020$  apply to  $\eta = 30^\circ$  to  $45^\circ$ , since at larger volume coefficients the slotted flap was not tested at small deflection angles. Also here considerable increase in  $\frac{\partial a}{\partial \eta}$  is noted with increasing  $c_j$ . Theoretical value (Glauert): 0.61.<sup>5</sup>

To ascertain any difference between values of  $c_a$  determined in tests with the blown-out volume being increased and value of  $c_a$  with volume being reduced, several  $c_a(c_j)$  curves have been obtained using both procedures. An instance of these tests (see fig. 28) shows that no difference can be observed; moreover, the same value of  $c_a$  was obtained for equal volume coefficients, regardless whether the volume was increased from zero or reduced from a high value.

Examples of pressure distribution along the slotted flap obtained for the purpose of flap-moment determination, are shown in figure 29, for various volume coefficients. Evidently unusually sharp peaks of low pressure may appear in the air-blowing procedure on the leading edge of the flap.

Figures 30 and 31 represent flap-moment coefficients  $c_r$  as function of  $c_j$  determined from pressure distributions, for various angles of attack. Within the range of the latter investigated, the magnitude of moment coefficient is increasing with volume of blown-out air, while it is almost independent of angle of attack.

<sup>5</sup> Translator's Note: -0.61

Conspicuous is the fact that toward higher values of  $\alpha_2$   $\alpha_r$  becomes smaller at  $\eta = 45^\circ$  than at  $\eta = 30^\circ$ . The cause of this phenomenon probably is that at large deflections the pressure peaks described above, shift further forward on the leading edge of the flap, producing shorter moment arm with respect to the hinge, thus reducing moment of the tangential force component.

Figures 32 to 35 represent the coefficient of normal force  $\alpha_{Nr}$  as well as that of tangential force  $\alpha_{Tr}$  as function of the volume coefficient.

## VI. CONCLUSIONS

Tests have been conducted to increase lift of a NACA 23012-64 airfoil, provided with slat, hinged nose and plain or slotted flap, by means of blowing out air from the wing. Air was blown out immediately in front of the flap, also, when in open position, immediately behind the hinged nose.

Using plain flap ( $\eta = 45^\circ$ ), at optimum slat position the lift coefficients obtained

No air being blown out,  $\alpha_2 = 0$   $\alpha_{a_{max}} = 2.18$

$\alpha_2 = 0.020$   $\alpha_{a_{max}} = 3.70$

Corresponding Values for Slotted Flap:

$\alpha_2 = 0$   $\alpha_{a_{max}} = 2.38$

$\alpha_2 = 0.020$   $\alpha_{a_{max}} = 4.0$

The effectiveness of the flap, indicated by  $\frac{\partial \alpha}{\partial \eta}$ , was considerably increased by blowing out air. For  $\alpha_a = 1$  and flap deflections up to  $\eta = 45^\circ$ , the following values were obtained:

$\alpha_2 = 0$   $\frac{\partial \alpha}{\partial \eta} = -0.271$   
 $\alpha_2 = 0.020$   $\frac{\partial \alpha}{\partial \eta} = -0.549$

The corresponding theoretical value is  $0.60^6$

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<sup>6</sup>Translator's Note: Presumably  $-0.60$ .



With Slotted Flap:

$$\begin{aligned} c_l &= 0 & \frac{\partial a}{\partial \eta} &= -0.270 \\ c_l &= 0.020 & \frac{\partial a}{\partial \eta} &= -0.601 \end{aligned}$$

Theoretical value:  $\frac{\partial a}{\partial \eta} = -0.61$

The slat produced no particular effects in comparison to a slat used on a wing with no boundary-layer control. Only a slight increase in  $c_{a_{max}}$  has been observed that could be attributed to the hinged nose. By blowing out air at the hinged nose, in addition, unseparated flow was maintained at larger angles of attack, increasing lift at the same time. Still, the highest lift coefficients were measured when the total available air volume was blown out at the flap only.

Translated by H. Pikler  
Goodyear Aircraft Corporation

## VII. REFERENCES

1. Ehlers/Schwier: Blasversuche an einem Flügel mit Spaltklappe.  
FB 1274.
2. Schwier: Versuche zur Auftriebssteigerung durch Ausblasen  
von Luft an einer symmetrischen Profil mit Wölkungs-  
klappe grosser Tiefe. FB 1462
3. Schwier: Ausblasversuche zur Auftriebssteigerung an einem  
Flügel von 9 % Dicke mit Vorflügel und Klappe. FB 1622.
4. Jacobs, Pinkerton, Greenberg: Tests of Related Forward-Camber  
Airfoils in the Variable-Density Wind Tunnel.  
NACA-Report 610 (1937).
5. Regenscheit: Messungen an einem Absaugeflügel mit und ohne  
Knicknase FB 1312.
6. Walz: Uebertragung gemessener Druckverteilungen auf beliebige  
Anstellwinkel. Luftfahrtforschung Bd. 16 (1939), S.121.
7. Keune: Auftrieb einer geknickten ebenen Platte. Luftfahrtforschung  
Bd. 13 (1936), S.85.
8. Regenscheit: Absaugeklappenflügel 23012, Teilbericht einer  
systematischer Dickenreihe. FB 1543.

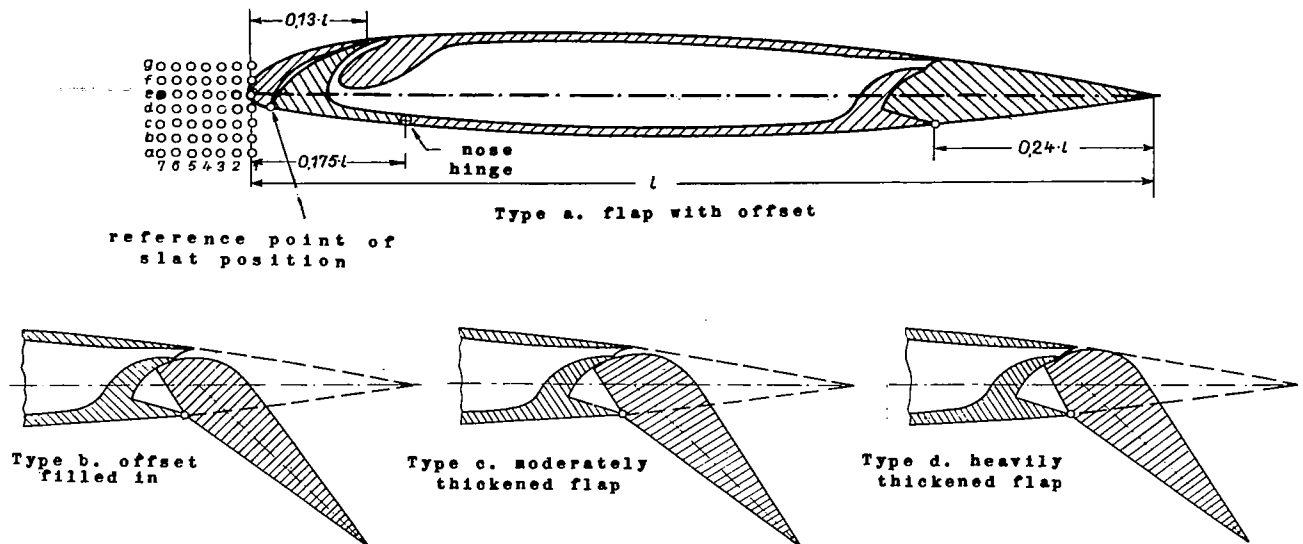


Fig. 1: 23012-64 airfoil with slat, hinged nose and plain flap; various types of plain flap, used at first in the tests.

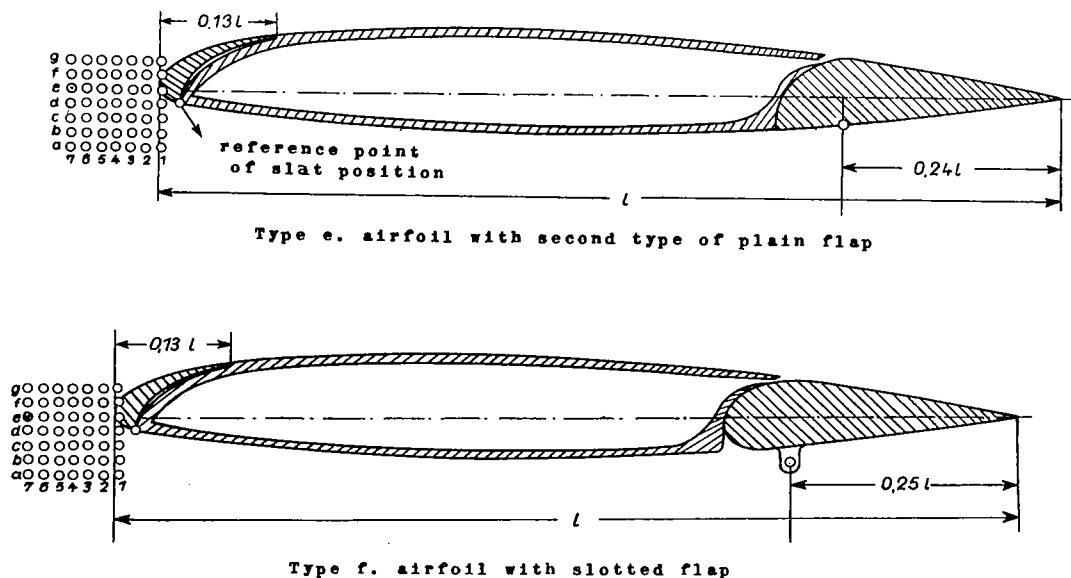


Fig. 2: 23012-64 airfoil with slat, second type of plain flap and slotted flap.

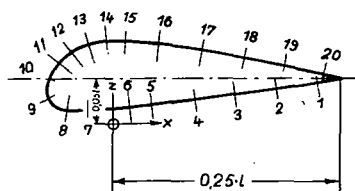


Fig. 2a: Slotted flap, type f; Position of pressure tubes.

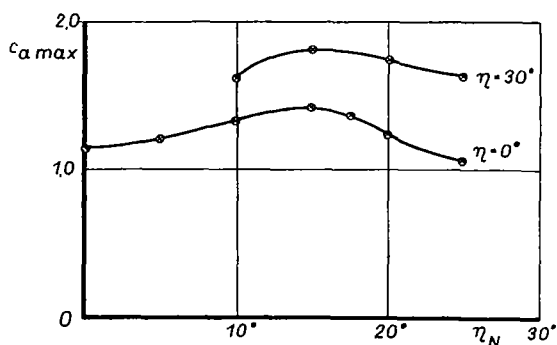
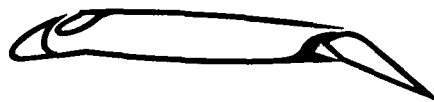


Fig. 3: Maximum lift vs. hinged nose angle  $\eta_N$  for wing with plain flap, type a; without blowing out air.



flow around wing  
unseparated

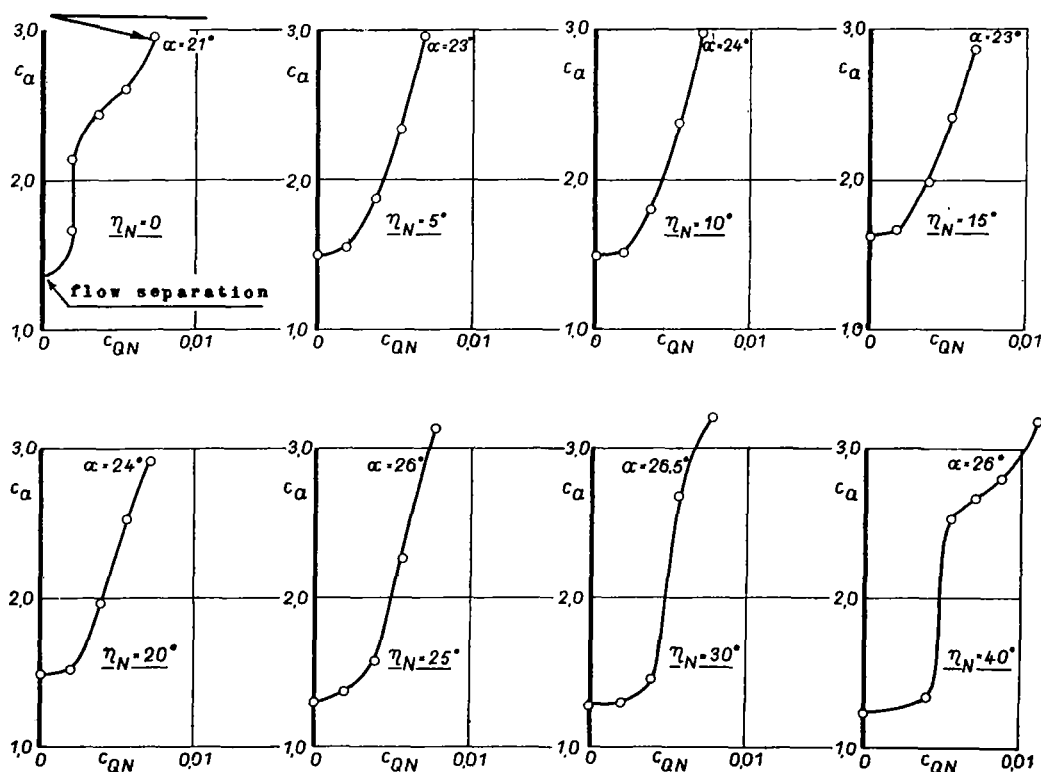


Fig. 4: Change of lift by blowing out air aft of hinged nose with plain flap type.

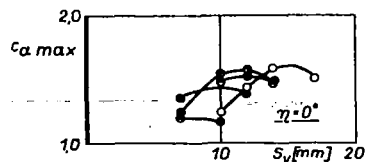


Fig. 5: Determination of most favorable slat position for wing with plain flap type b, without blowing out air.

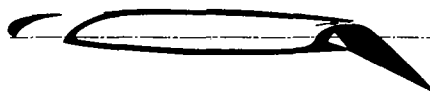
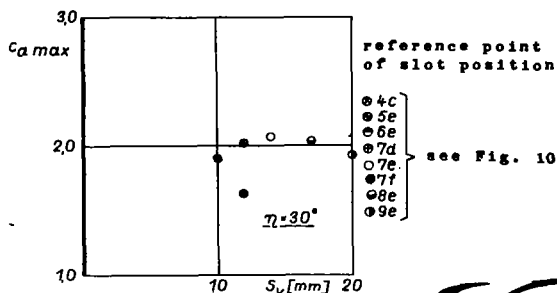


Fig. 6: Wing with plain flap type b; offset on flap filled in;  $s = .00667l$ ; slat position: 7e(14)

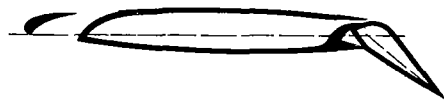
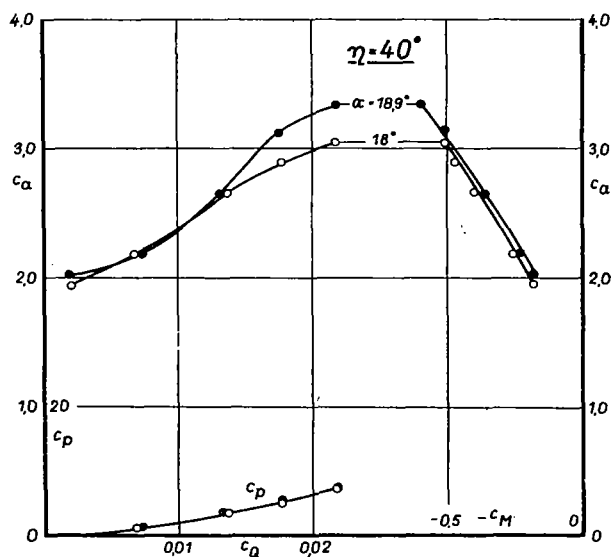
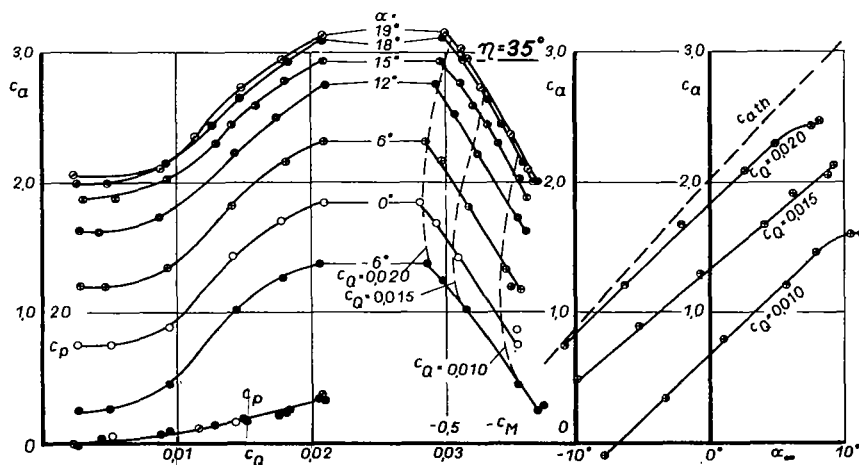


Fig. 7: Wing with plain flap type c; "moderately thickened" flap;  $s = .0067l$ ; slat position: 7e(14)

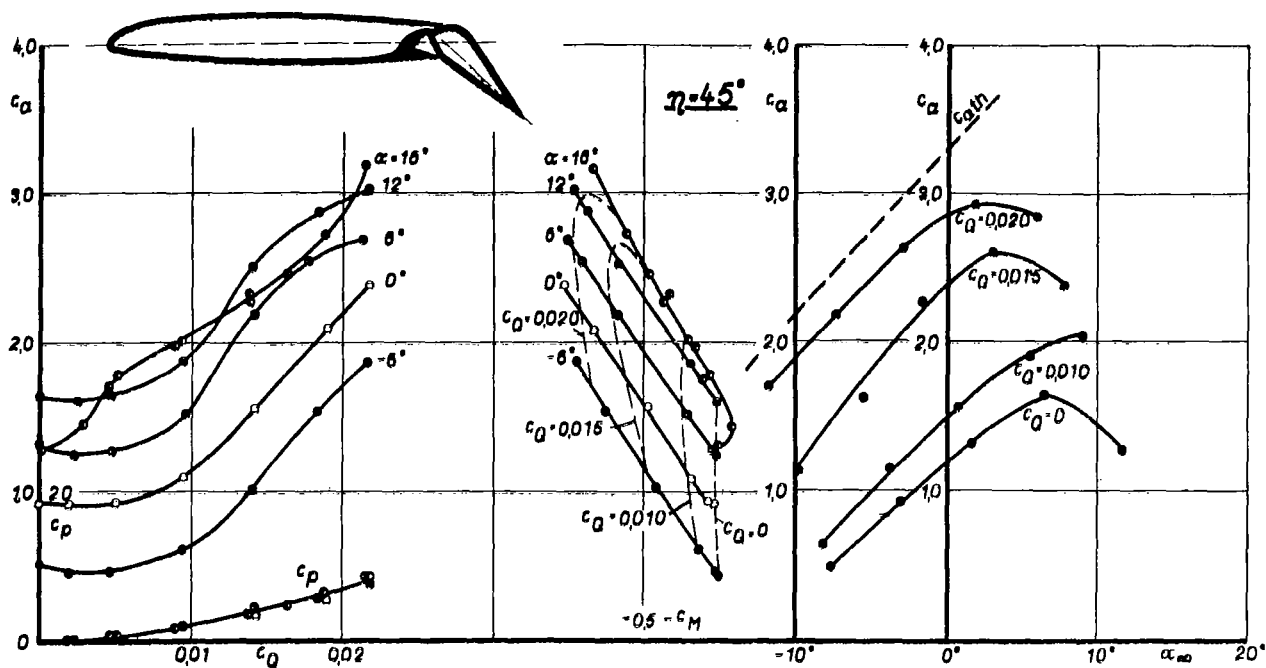


Fig. 8: Wing with plain flap type d; flap "heavily thickened"  
 $s = .00667l$ ; slat closed.

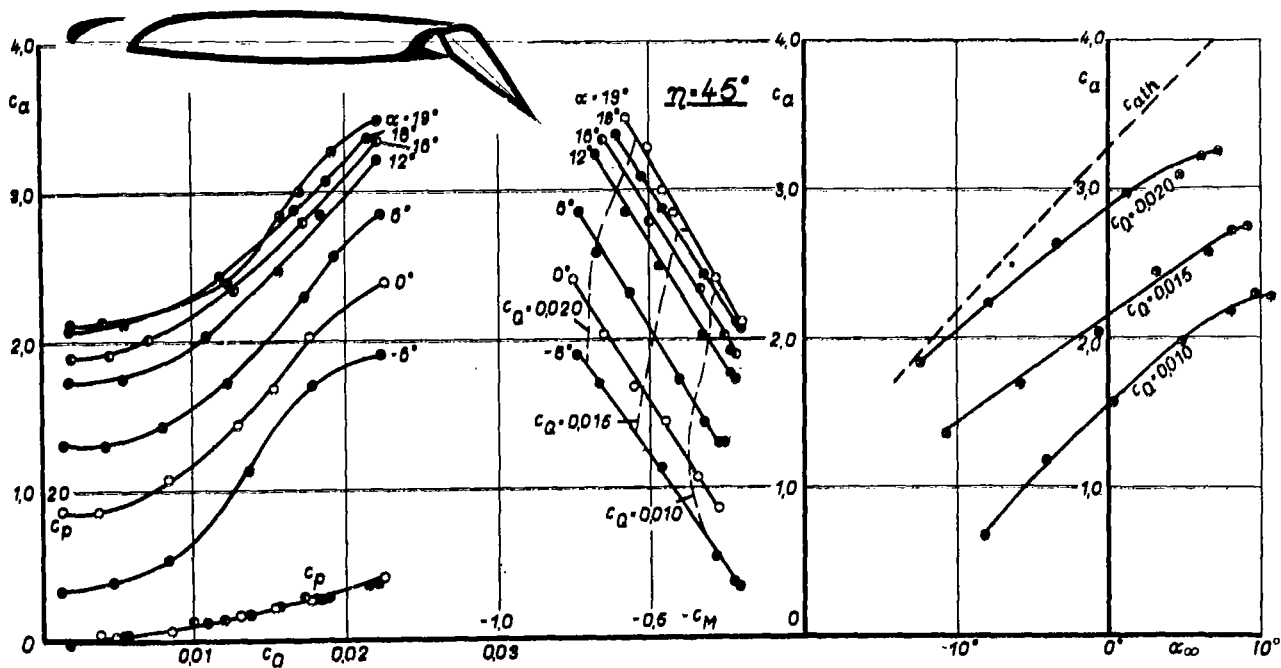


Fig. 9: Wing with plain flap type d; "heavily thickened" flap;  
 $s = .00667l$ ; slat in position 7e(14).

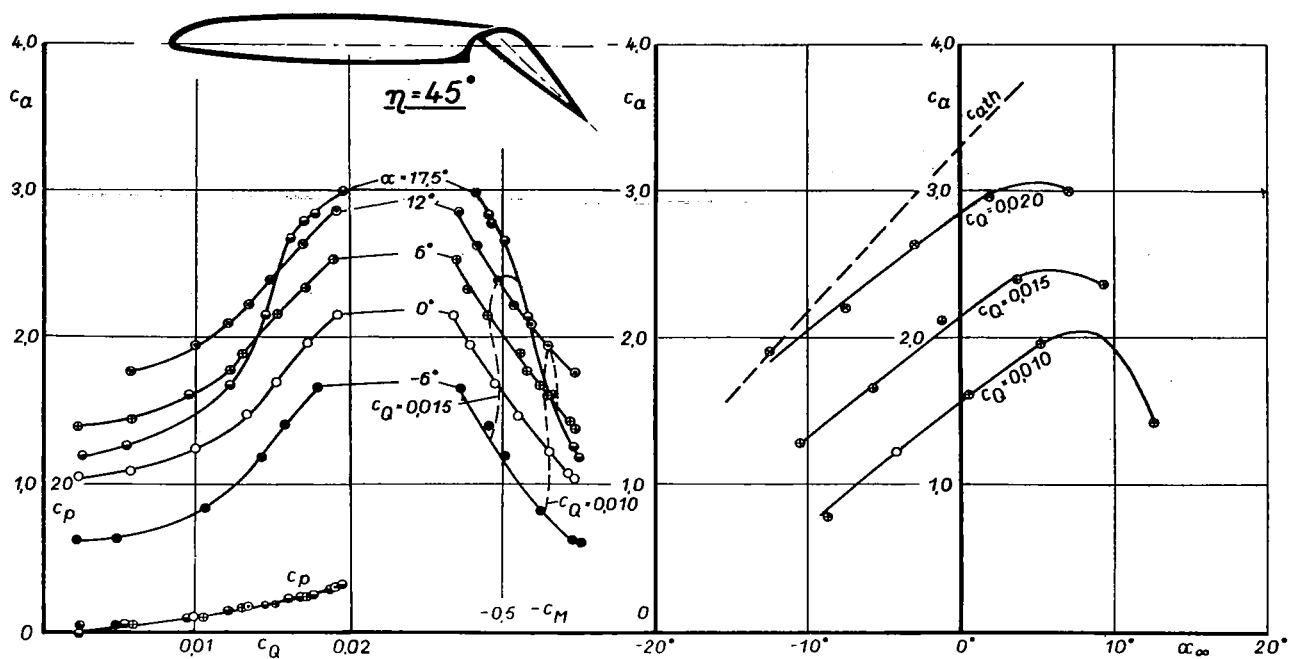


Fig. 10: Wing with plain flap type e; hinge in 0-position;  
 $s = .00667$ ; slat closed.

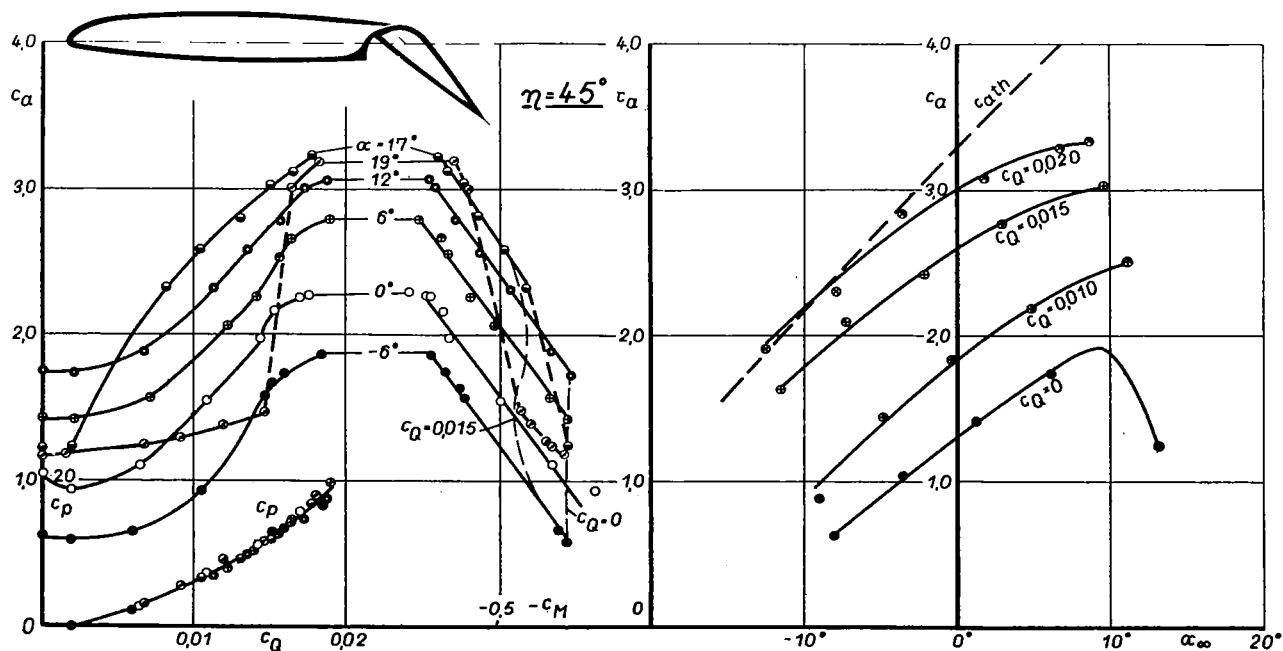


Fig. 11: Wing with plain flap type e; hinge in 0-position;  $s = .0055$ ;  
 slat closed.

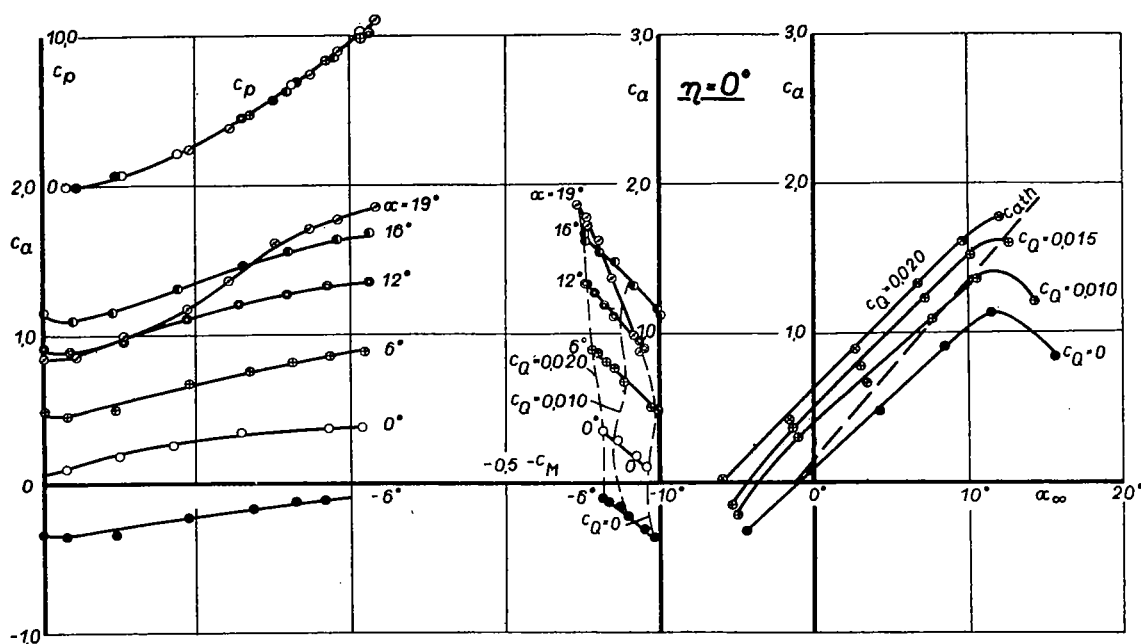


Fig. 12: Wing with plain flap type e; hinge position displaced;  
 $s = .00667l$ ; slat closed.

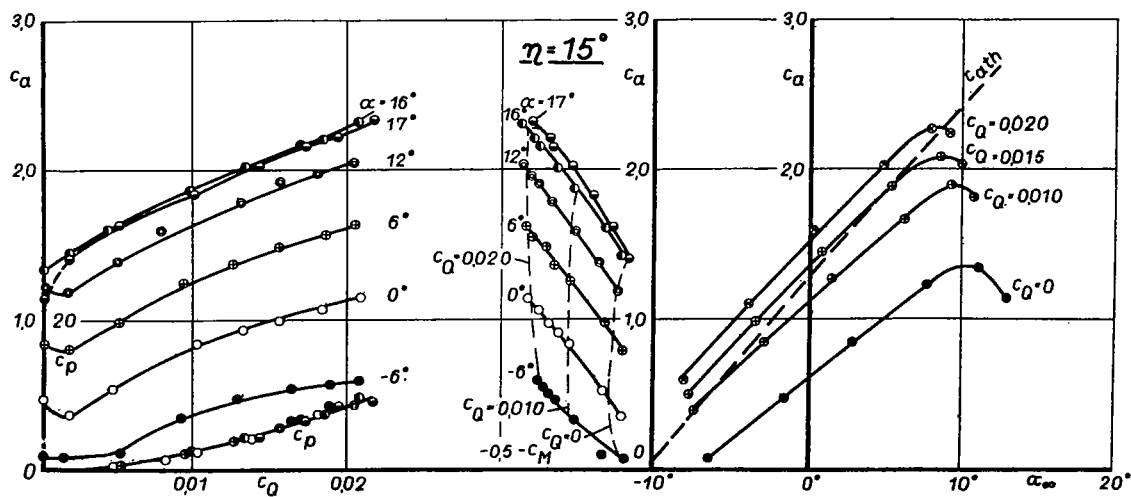


Fig. 13: Wing with plain flap type e; hinge position displaced;  
 $s = .00667l$ ; slat closed.



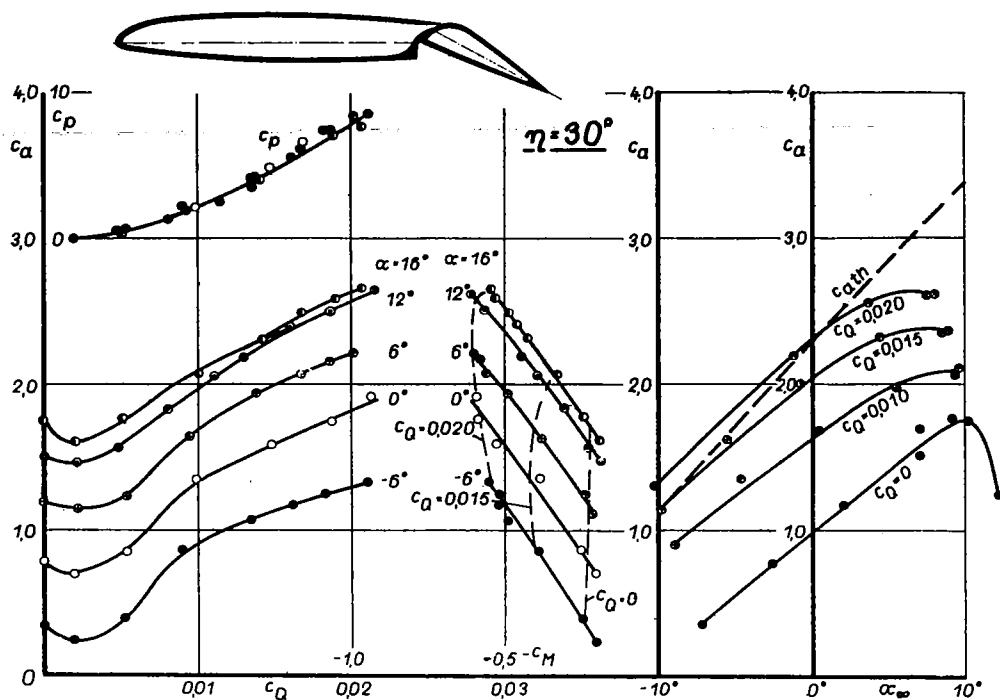


Fig. 14: Wing with plain flap type e; hinge position displaced;  $s = .00667l$ ; slat closed.

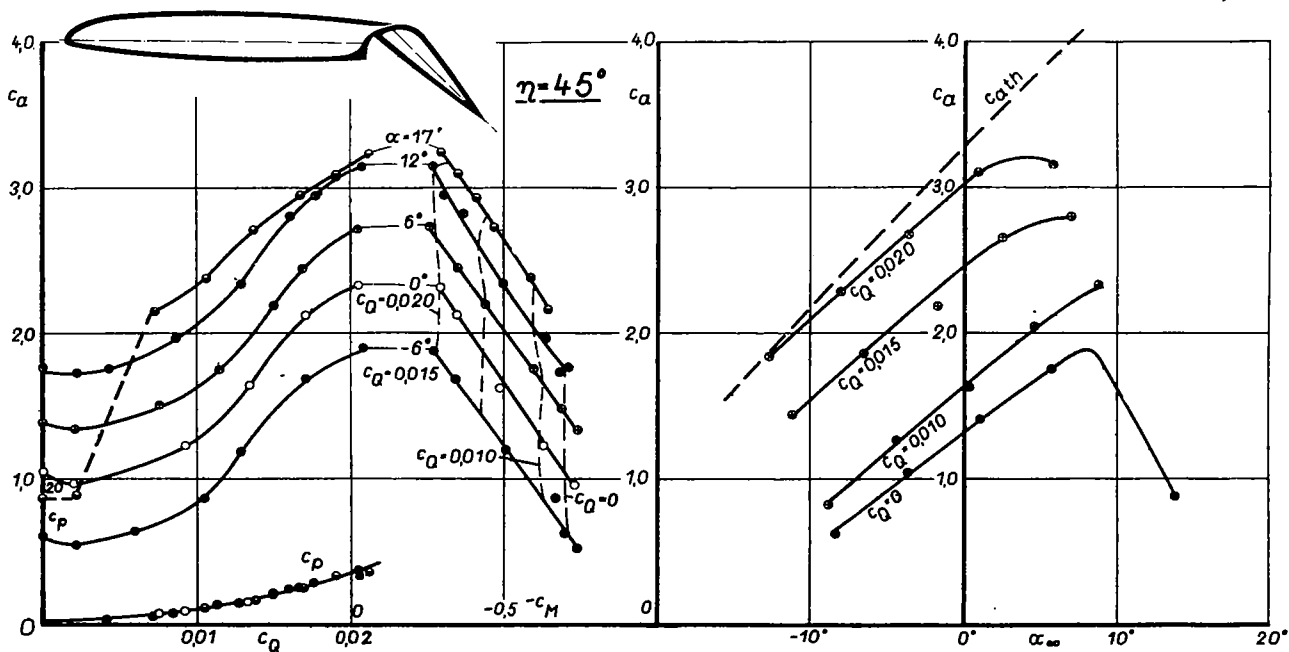


Fig. 15: Wing with plain flap type e; hinge position displaced;  $s = .00667l$ ; slat closed.

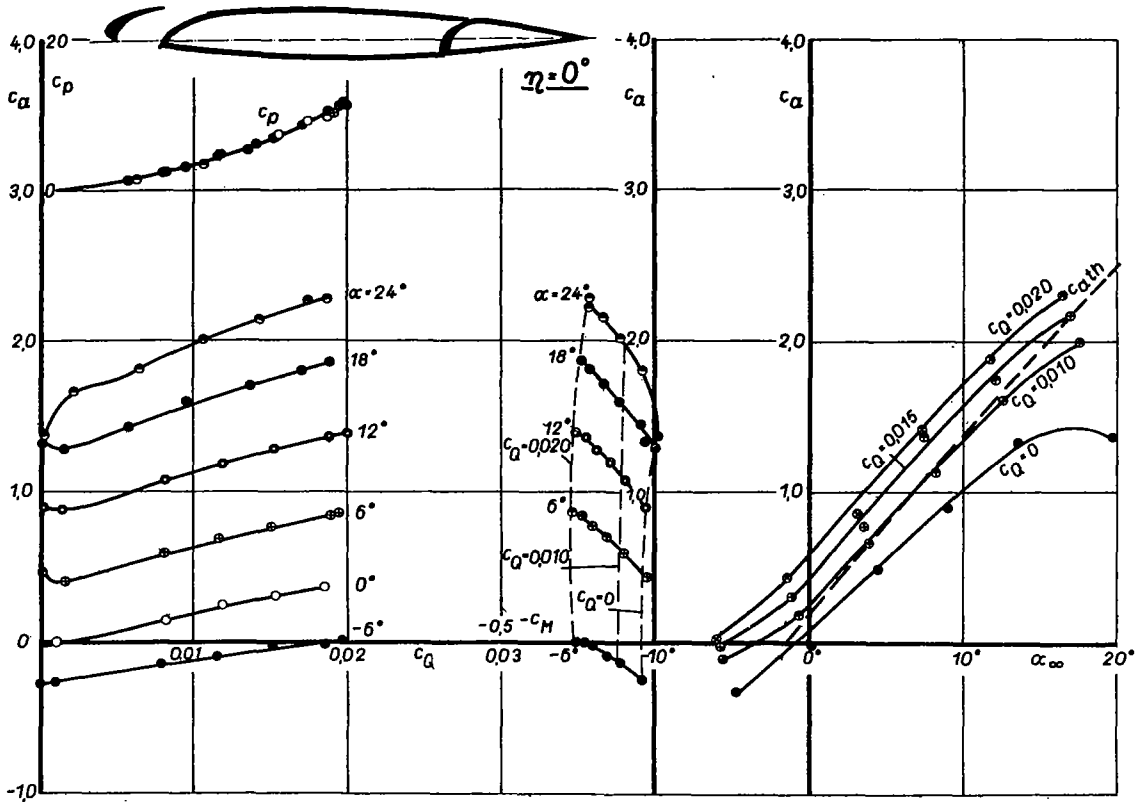


Fig. 16: Wing with plain flap type e; hinge position displaced;  $s = .00667l$ ; slat position  $6e(16)$ .

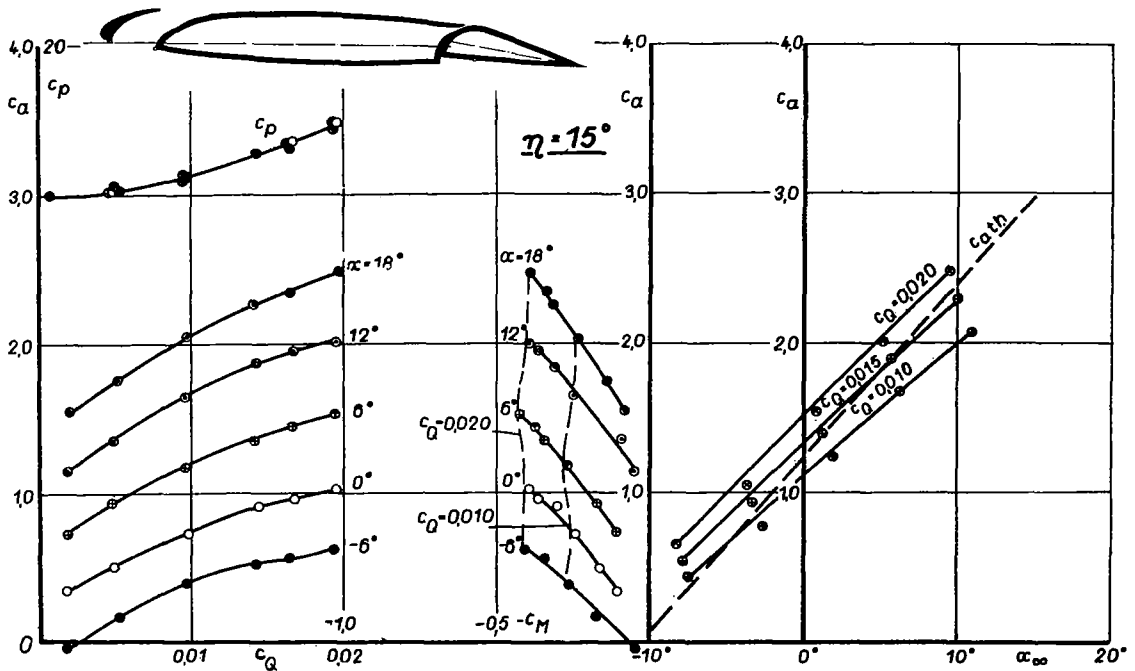


Fig. 17: Wing with plain flap type e; hinge position displaced;  $s = .00667l$ ; slat position;  $6e(16)$ .

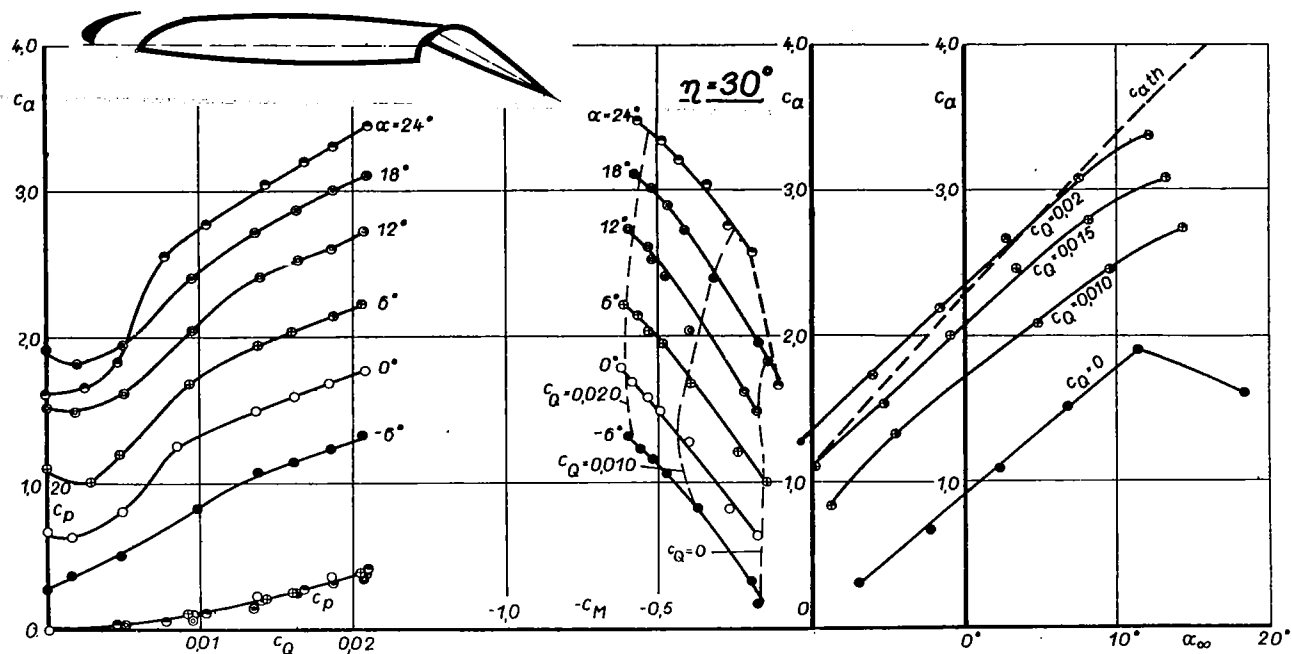


Fig. 18: Wing with plain flap type e; hinge position displaced;  
 $s = .00667l$ ; slat position  $6e(16)$ .

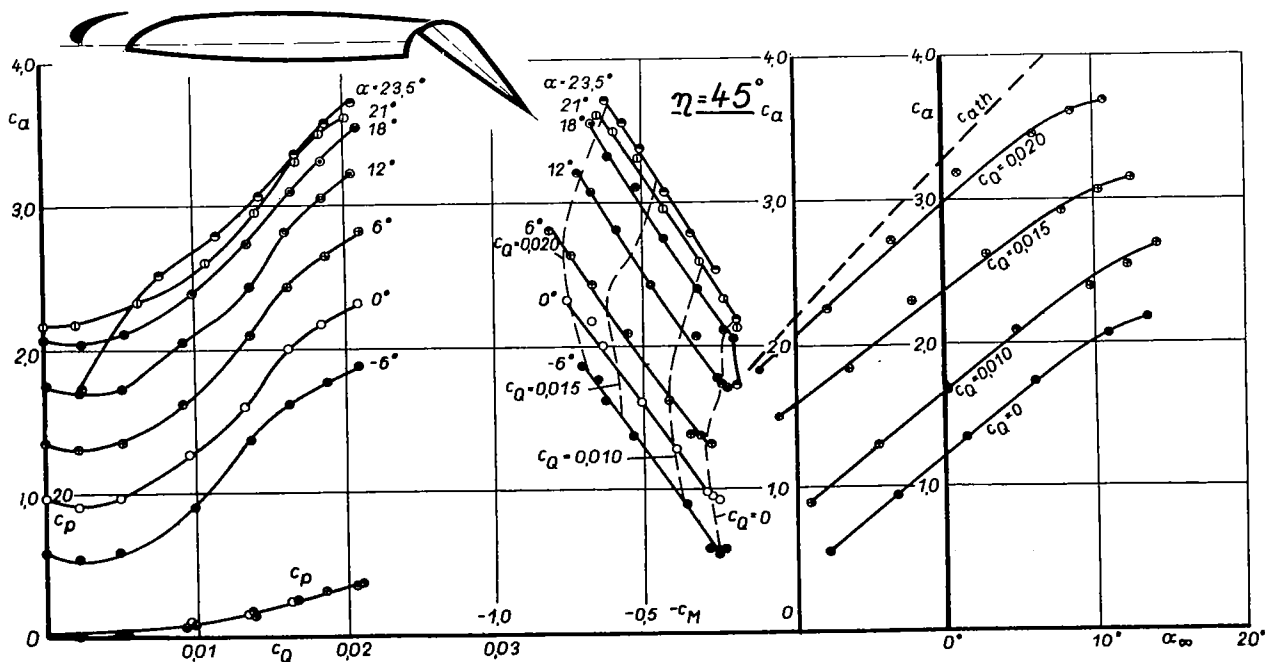
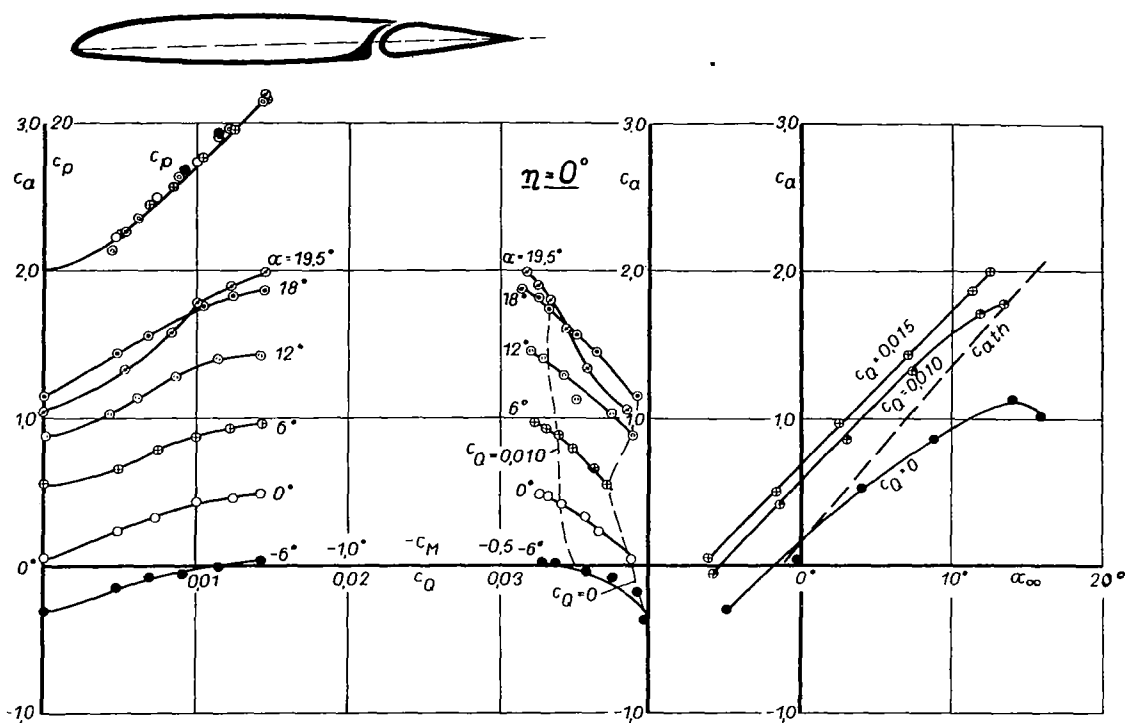
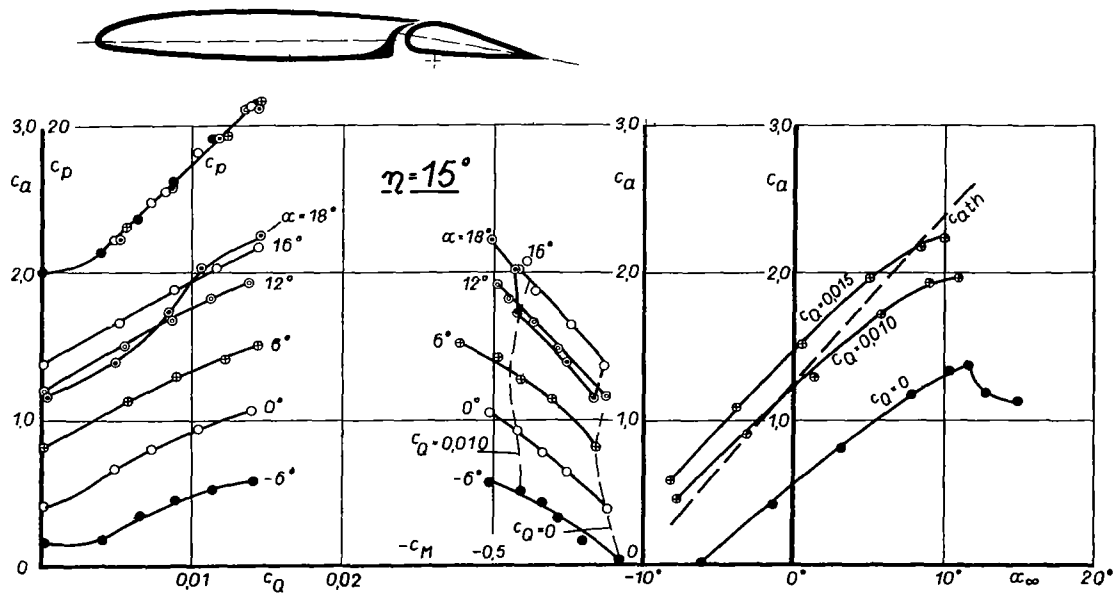


Fig. 19: Wing with plain flap type e; hinge position displaced;  
 $s = .00667l$ ; slat position  $6e(16)$ .

Fig. 20: Wing with slotted flap type f;  $s = .005 l$ ; slat closed.Fig. 21: Wing with slotted flap type f;  $s = .005 l$ ; slat closed.

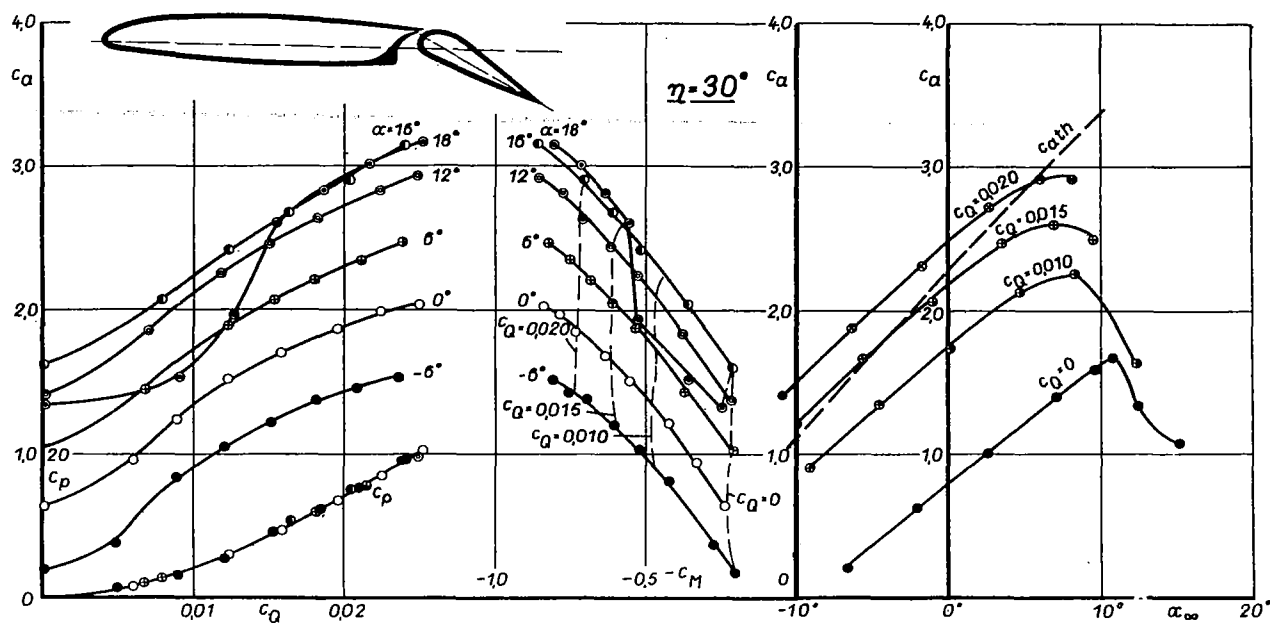


Fig. 22: Wing with slotted flap type f;  $s = 0.0051$ ; slat closed.

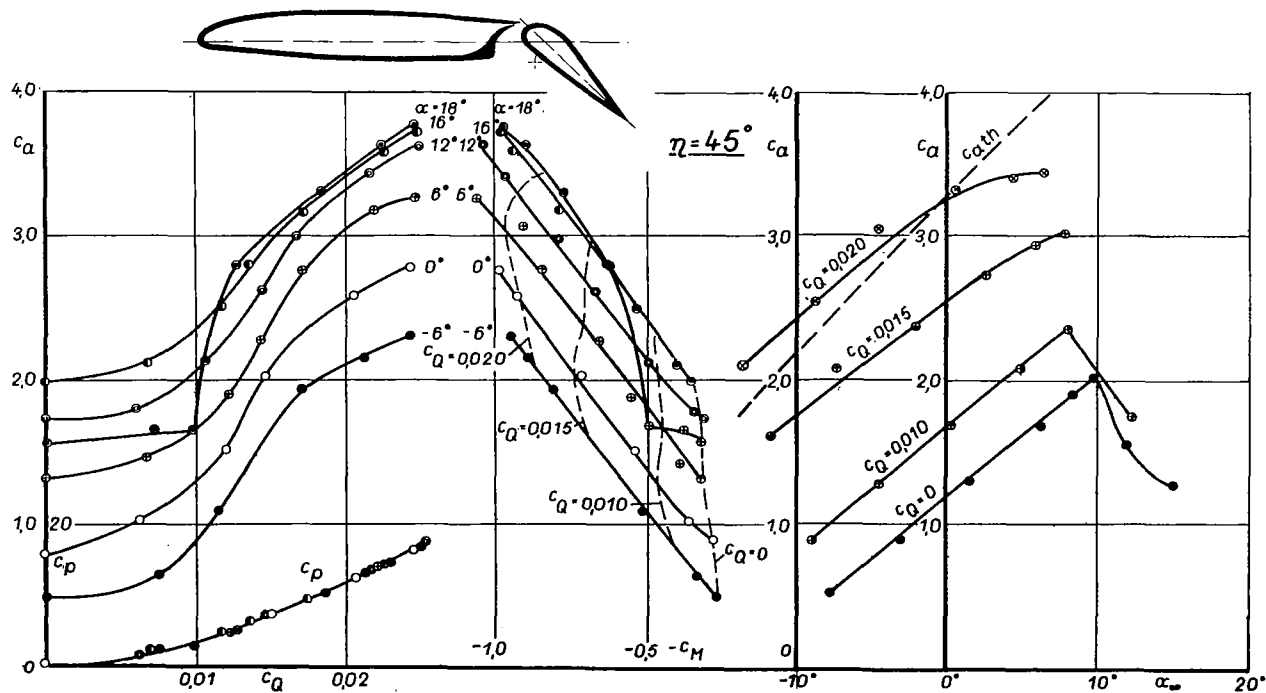


Fig. 23: Wing with slotted flap type f;  $s = 0.0051$ ; slat closed.

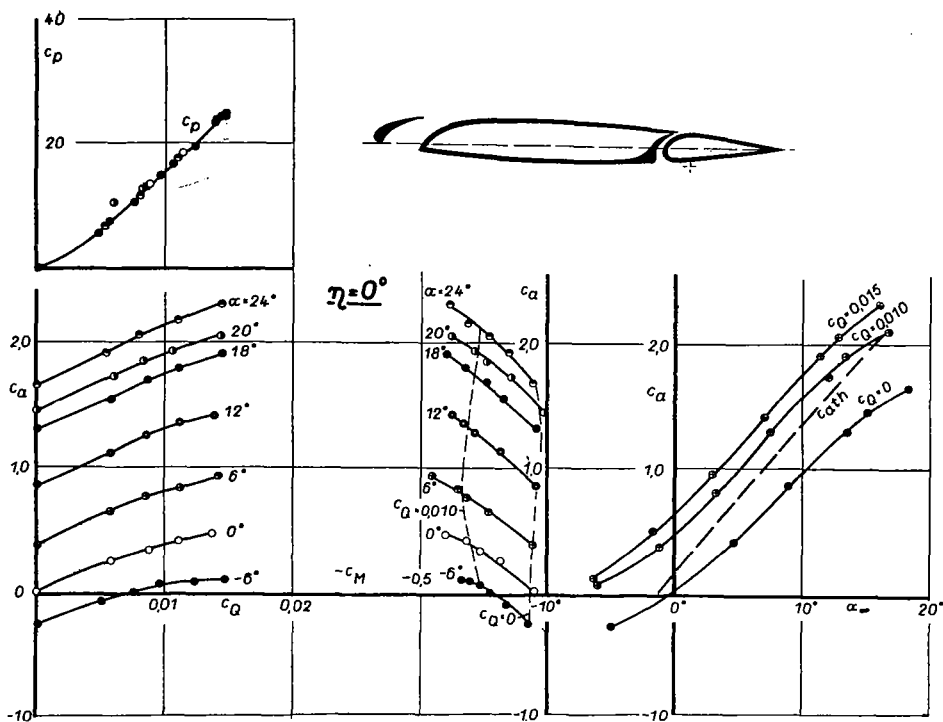


Fig. 24: Wing with slotted flap type f;  $s = .005l$ ;  
slat position  $6e(16)$ .

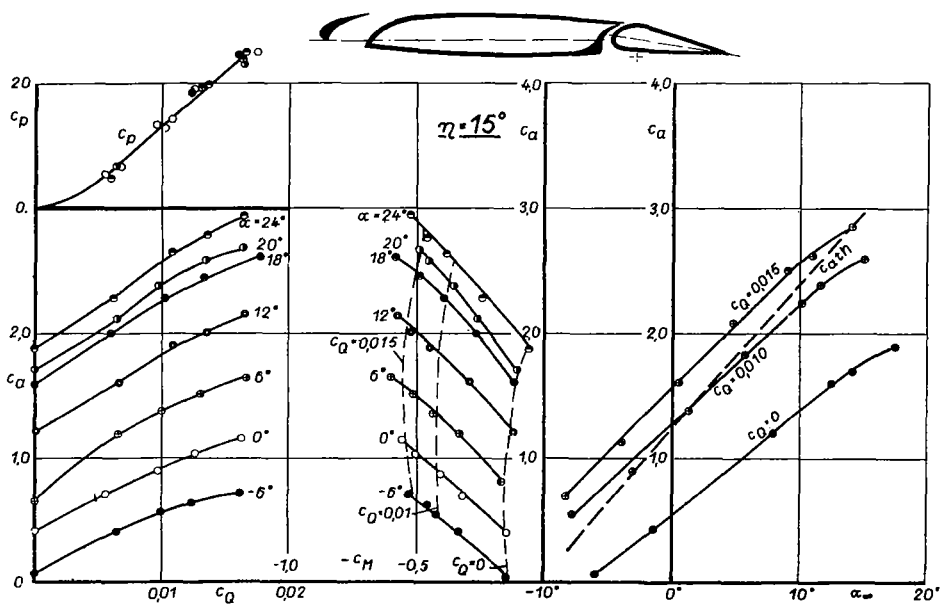


Fig. 25: Wing with slotted flap type f;  $s = .005l$ ;  
slat position  $6e(16)$ .

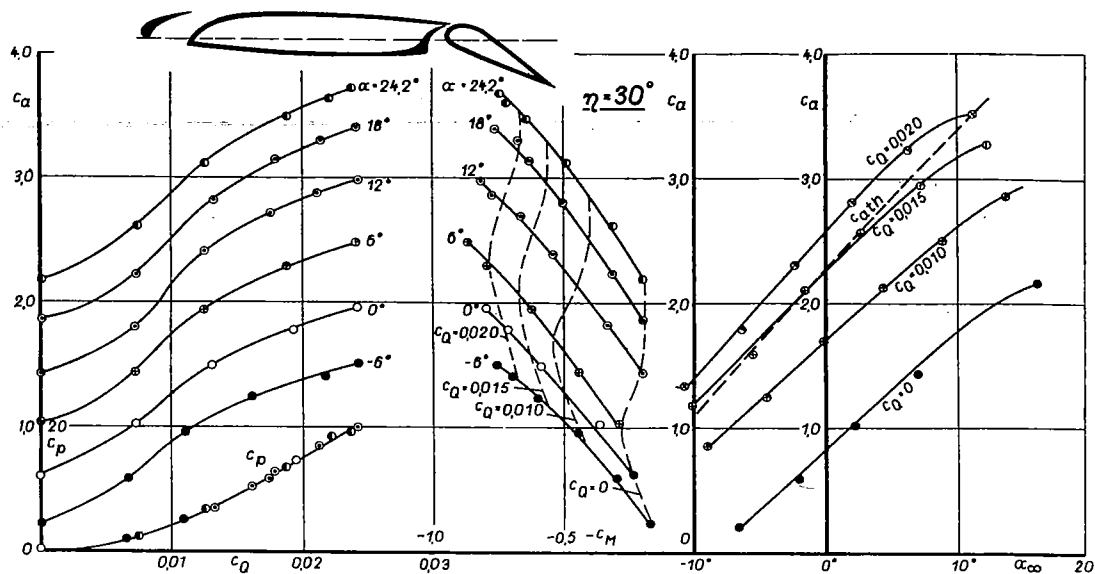


Fig. 26: Wing with slotted flap type f;  $s = .005l$ ; slat position 6e(16).

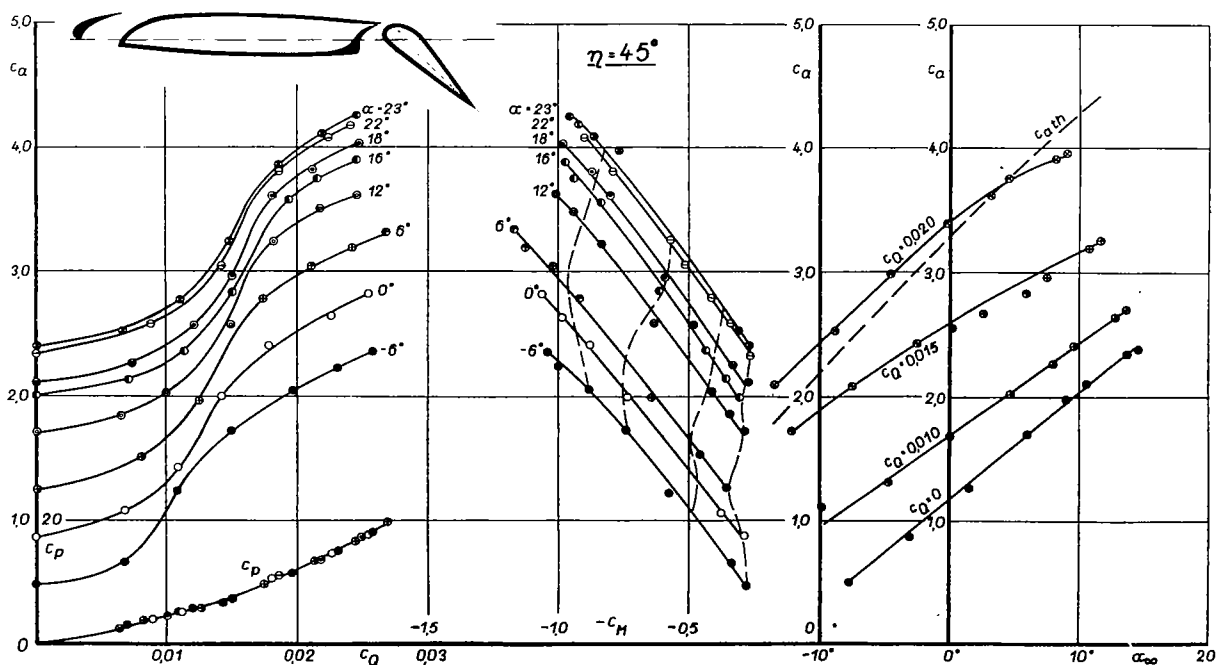


Fig. 27: Wing with slotted flap type f;  $s = .005l$ ; slat position 6e(16).

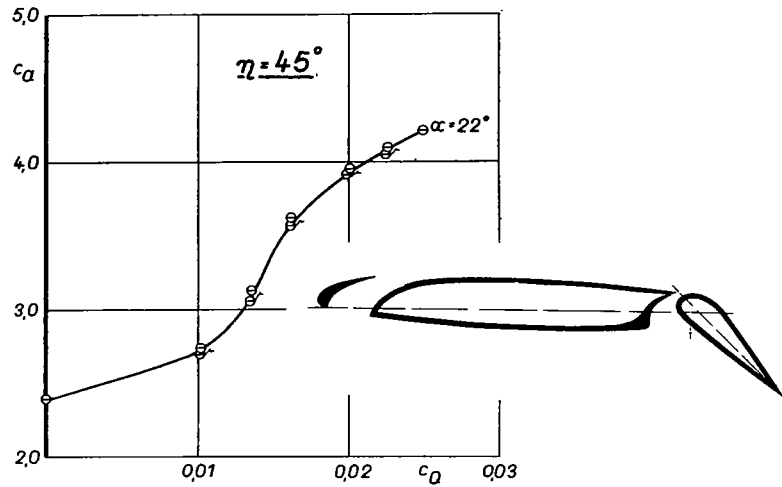


Fig. 28: Wing with slotted flap type f;  $s = .005l$ ; slat position  $6e(16)$ ; Test run at increasing and decreasing volume  $n = 30^\circ$ .

$\eta = 30^\circ$

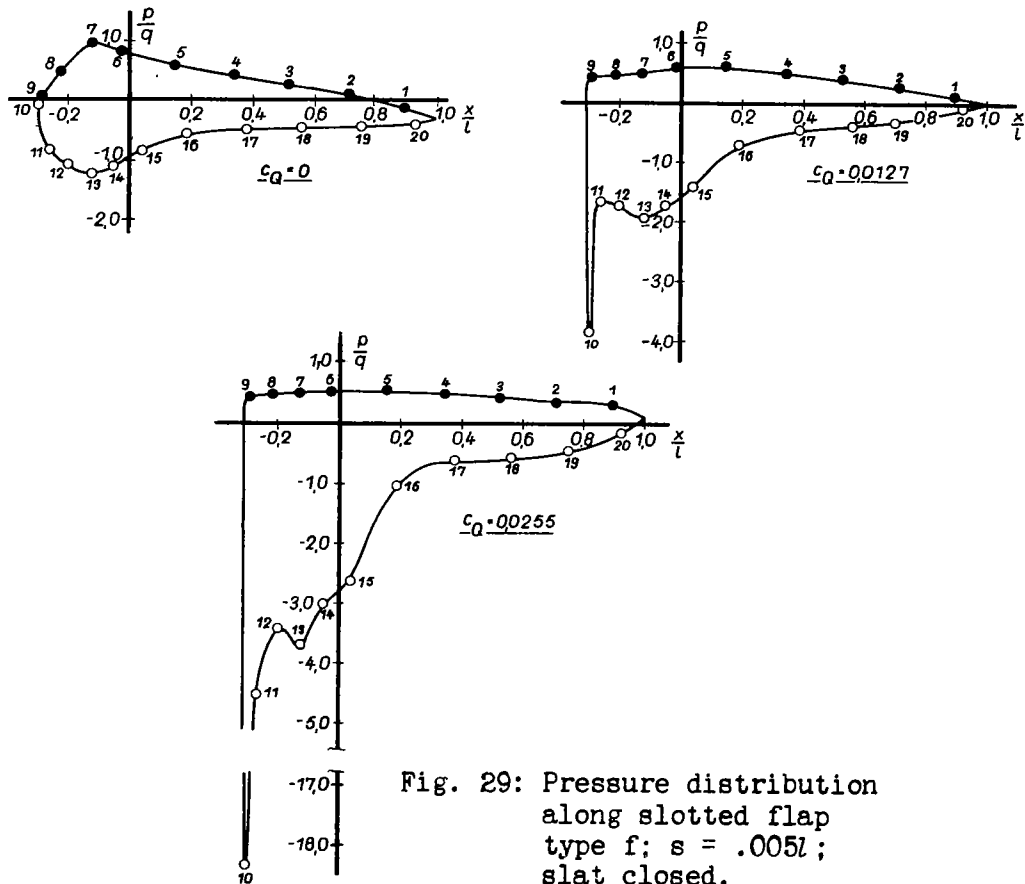


Fig. 29: Pressure distribution along slotted flap type f;  $s = .005l$ ; slat closed.



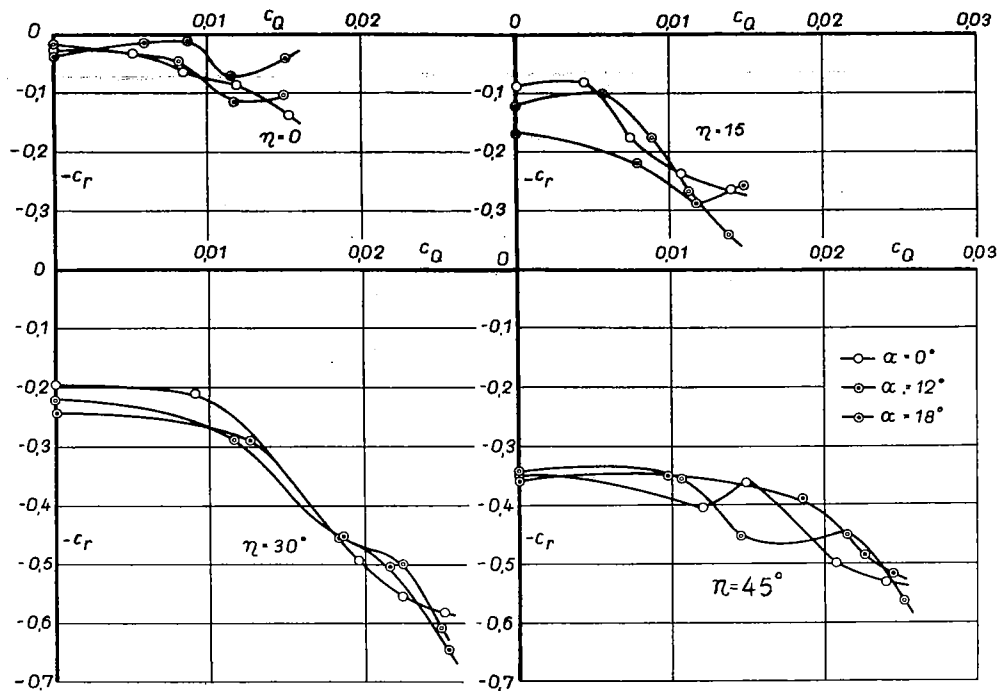


Fig. 30: Wing with slotted flap type f;  $s = .005l$ ; slat closed.

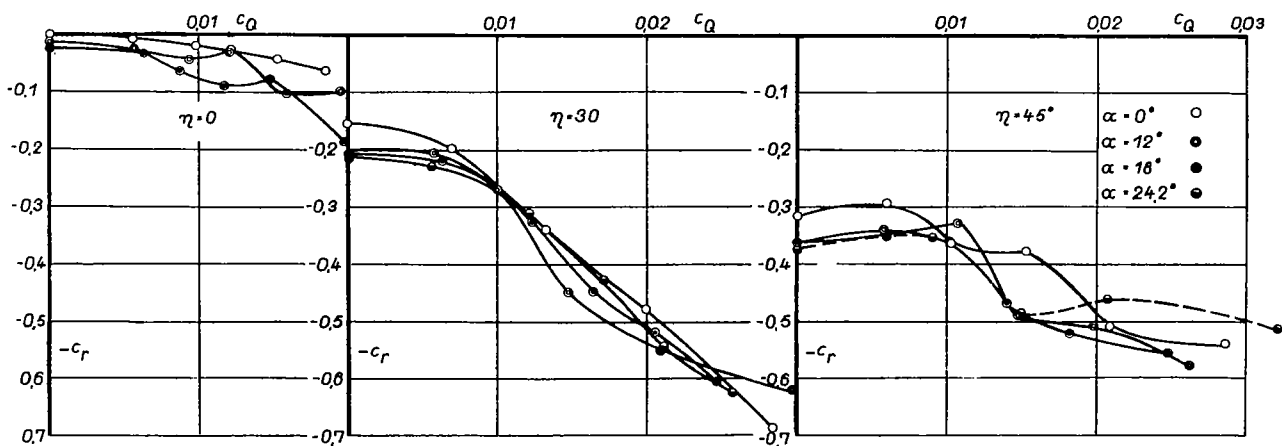


Fig. 31: Wing with slotted flap type f;  $s = .005l$ ; slat closed.

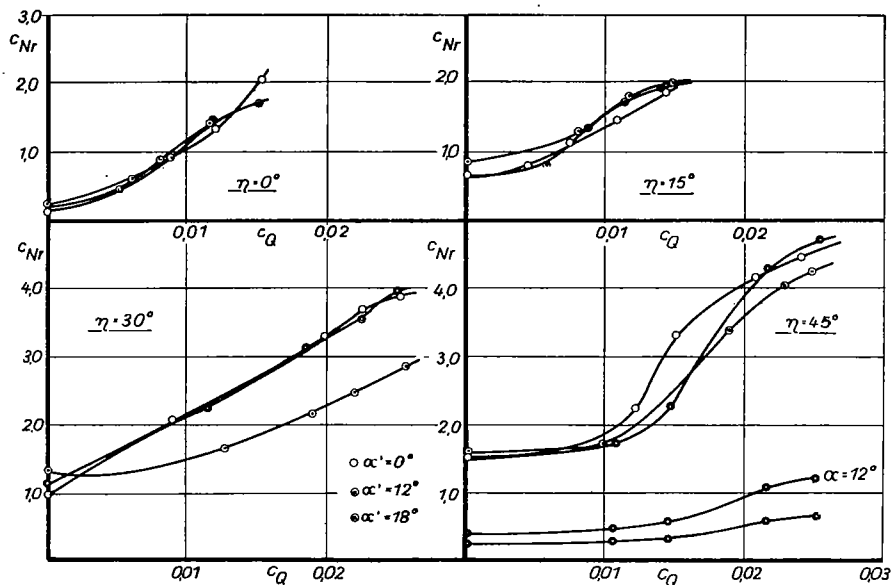


Fig. 32: Slotted flap normal force coefficients  
type f;  $s = .005$ ; slat closed.

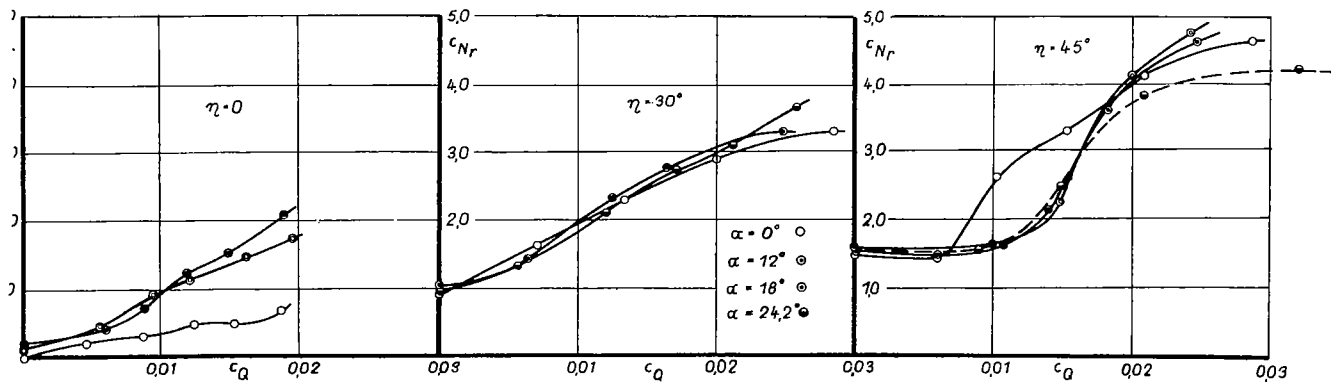


Fig. 33: Slotted flap normal force coefficients  
type f;  $s = .005$ ; slat open.

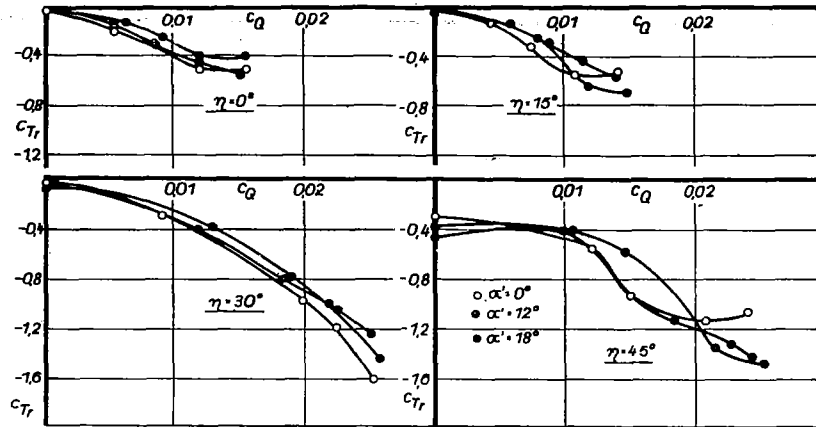


Fig. 34: Slotted flap tangential force coefficients  
type f;  $s = .005l$ ; slat closed.

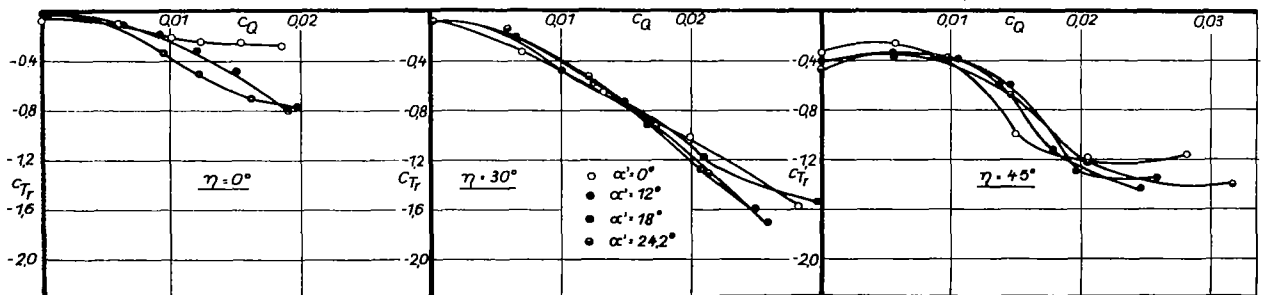


Fig. 35: Slotted flap tangential force coefficients  
type f;  $s = .005l$ ; slat open.